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An effective hybrid biogeography-based optimization algorithm for the distributed assembly permutation flow-shop scheduling problem

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ABSTRACT

Distributed assembly permutation flow-shop scheduling problem (DAPFSP) is widely exists in modern supply chains and manufacturing systems. In this paper, an effective hybrid biogeography-based optimization (HBBO) algorithm that integrates several novel heuristics is proposed to solve the DAPFSP with the objective of minimizing the makespan. Firstly, the path relinking heuristic is employed in the migration phase as product local search strategy to optimize the assembly sequence. Secondly, an insertion-based heuristic is used in the mutation phase to determine the job permutation for each product. Then, a novel local search method is designed based on the problem characteristics and embedded in the HBBO scheme to further improve the most promising individual. Finally, computational simulations on 900 small-sized instances and 810 large-sized instances are conducted to demonstrate the effectiveness of the proposed algorithm, and the new best known solutions for 162 instances are found.

1. Introduction

The permutation flow-shop scheduling problem (PFSP) is a widely investigated combinatorial optimization problem and plays a very important role in manufacturing systems and industrial processes. The PFSP has been proven to be an NP-hard problem when the number of machines was more than three (Gonzalez & Sahni, 1978). After the pioneering work of Johnson (Johnson, 1954), many approaches have been proposed to solve the PFSP (Chang & Chen, 2014; Chang, Chen, Tiwari, & Iquebal, 2013; Chang, Huang, & Ting, 2011; Chang, Huang, Wu, & Cheng, 2013; Chen, Chang, & Lin, 2014; Chen, Chen, Chang, & Chen, 2012; Fernandez-Viagas & Framinan, 2014; Hsu, Chang, & Chen, 2015; Lin, 2015b; Liu & Liu, 2013; Xu, Yin, Cheng, Wu, & Gu, 2014). A single production center or factory is the common assumption among these studies, and all jobs in the permutation are assigned to the same factory. However, production systems with more than one production center (namely, a distributed manufacturing systems) is more common (Moon, Kim, & Hur, 2002; Wang & Shen, 2007) since it can achieve higher product quality while reducing production costs and management risks (Chan, Chung, & Chan, 2005). Scheduling in distributed systems is more complicated than in regular shop scheduling problems; in particular, job allocation to factories and job scheduling at each factory must be considered simultaneously when making decisions.

A number of evolutionary algorithms have been proposed over the past few years, e.g., genetic algorithms (Reeves, 1995), particle swarm optimization (Tasgetiren, Liang, Sevkli, & Gencyilmaz, 2007), artificial bee colony algorithms (Tasgetiren, Pan, Suganthan, & Chen, 2011), and differential evolution algorithms (Pan, Tasgetiren, & Liang, 2008). However, very few have been applied to distributed system problems (De Giovanni & Pezzella, 2010; Gao & Chen, 2011; Wang, Wang, Liu, & Xu, 2013). Very recently, an extension of the regular PFSP called the distributed assembly permutation flow-shop scheduling problem (DAPFSP) was introduced by Hatami, Ruiz, and Andrés-Romano (2013), where a set of products and a set of factories are combined with the regular PFSP. Each job in the DAPFSP belongs to one product and is processed in one factory. All products are assembled in a single assembly factory with an assembly machine. Hatami et al. also considered the minimization of the maximum completion time at the assembly factory (Hatami et al., 2013).

Inspired by the immigration and emigration process of species among habitats, a biogeography-based optimization (BBO) was proposed by Simon (2008). BBO has demonstrated good performance when compared with other evolutionary algorithms (Bhattacharya & Chattopadhyay, 2011; Jamuna & Swarup, 2011; Lin, 2014, 2015a; Lin, Xu, & Zhang, 2014; Ma & Simon, 2011). To the best of our knowledge, there is no reported work on BBO for solving the DAPFSP. Our goal is to employ an effective hybrid

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biogeography-based optimization (HBBO) algorithm to solve the DAPFSP with the objective of minimizing the makespan, i.e., the maximum completion time. In particular, the path relinking technique is employed as a migration operation, and an insertion-based heuristic is presented to modify the mutation operator. Moreover, a novel local search method is also developed and embedded in the HBBO to enhance the searching ability. Experiments are conducted on 900 small-sized instances and 810 large-sized instances, which were generated by Hatami et al. (2013), to verify the effectiveness of the proposed hybrid scheme.

The remainder of this paper is organized as follows. In Sections 2 and 3, the DAPFSP and the original BBO are introduced, respectively. In Section 4, the HBBO scheme is proposed for the DAPFSP. The computational results on benchmark instances, together with a comparison to other heuristic algorithms, are presented in Section 5. Finally, conclusions are drawn in Section 6.

2. Distributed assembly permutation flow-shop scheduling problem

As illustrated in Fig. 1, the DAPFSP is a combination of the distributed PFSP and the assembly flow-shop scheduling problem, which consists of two stages (production and assembly) and can be generalized into three sub-problems: job scheduling, product scheduling and factory assignment. The notations used in the optimization model of DAPFSP are presented in Table 1.

The first stage consists of n jobs $\{J_1, J_2, \ldots, J_n\}$ that must be processed in F identical factories. All factories are capable of processing all jobs, and each factory is a PFSP with m machines $\{M_1, M_2, \ldots, M_m\}$. A job J_i is formed by a sequence of operations $\{O_{i1}, O_{i2}, \ldots, O_{im}\}$ that are processed one after another on m machines. The second stage is a single assembly factory with an assembly machine M_A, which assembles jobs by using a defined assembly program to make H different final products $\{P_1, P_2, \ldots, P_H\}$. Each product P_h has N_h jobs, and these jobs need to be processed in the factories before assembling product P_h; hence, $\sum_{h=1}^{H} N_h = n$. In this paper, the maximum completion time (makespan) at the assembly factory is the objective to minimize.

Let $\gamma_h^f = [\gamma_h^f(1), \gamma_h^f(2), \ldots, \gamma_h^f(n_h^f)]$ be the sequence of jobs in factory $f (f = 1, \ldots, F)$ that belong to product P_h, where n_h^f $(n_h^f < N_h)$ is the total number of jobs in product P_h assigned to factory f. $C_{M_A,h}$ and $C_{i,j}$ denote the completion time of product P_h on assembly machine M_A and the operation O_{ij} on machine M_j, respectively. For a schedule Λ of the DAPFSP, i.e., a set of sequences $\{\gamma_1^f, \gamma_2^f, \ldots, \gamma_H^f\}$, the makespan $C_{\max}(\Lambda)$ is given by:

$$C_{\gamma_h^f(1),1} = p_{\gamma_h^f(1),1}, \quad f = 1, 2, \ldots, F; \quad h = 1, 2, \ldots, H, \tag{1}$$

$$C_{\gamma_h^f(k),1} = C_{\gamma_h^f(k-1),1} + p_{\gamma_h^f(k),1}, \quad f = 1, 2, \ldots, F; \quad k = 1, 2, \ldots, n_h^f; \quad h = 1, 2, \ldots, H, \tag{2}$$

$$C_{\gamma_h^f(1),j} = C_{\gamma_h^f(1),j-1} + p_{\gamma_h^f(1),j}, \quad f = 1, 2, \ldots, F; \quad j = 1, 2, \ldots, m; \quad h = 1, 2, \ldots, H, \tag{3}$$

$$C_{\gamma_h^f(k),j} = \max\left\{C_{\gamma_h^f(k-1),j}, C_{\gamma_h^f(k),j-1}\right\}, \quad f = 1, 2, \ldots, F; \quad k = 2, \ldots, n_h^f; \quad j = 1, 2, \ldots, m; \quad h = 1, 2, \ldots, H, \tag{4}$$

Table 1
The notations used in the optimization model for the DAPFSP.

Indices	
i	Index for jobs where $i = 1, \ldots, n$
j	Index for machines where $j = 1, \ldots, m$
h	Index for products where $h = 1, \ldots, H$
f	Index for factories where $f = 1, 2, \ldots, F$
k	Index for jobs in product P_h assigned to factory f where $k = 2, \ldots, n_h^f$
Parameters	
n	The number of jobs
m	The number of machines
F	The number of factories
H	The number of products
p_{ij}	The processing time of operation O_{ij} on machine M_j
N_h	The number of jobs belongs to product P_h
Q_h	The processing time to assemble product P_h
Λ	A given feasible schedule
Variables	
n_h^f	The total number of jobs in product P_h assigned to factory f
γ_h^f	The sequence of jobs in factory f that belong to product P_h where $\gamma_h^f = \left[\gamma_h^f(1), \gamma_h^f(2), \ldots, \gamma_h^f(n_h^f)\right]$
$C_{i,j}$	The completion time of operation O_{ij} on machine M_j
$C_{M_A,h}$	The completion time of product P_h on assembly machine M_A
$C_{\max}$	Makespan value

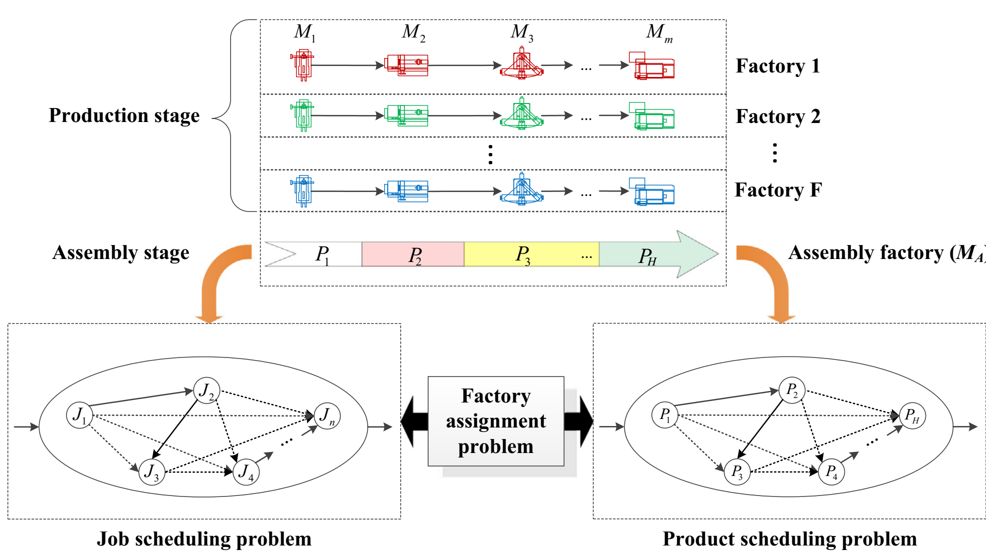

Fig. 1. Illustration of the DAPFSP.